AN2390
Application note

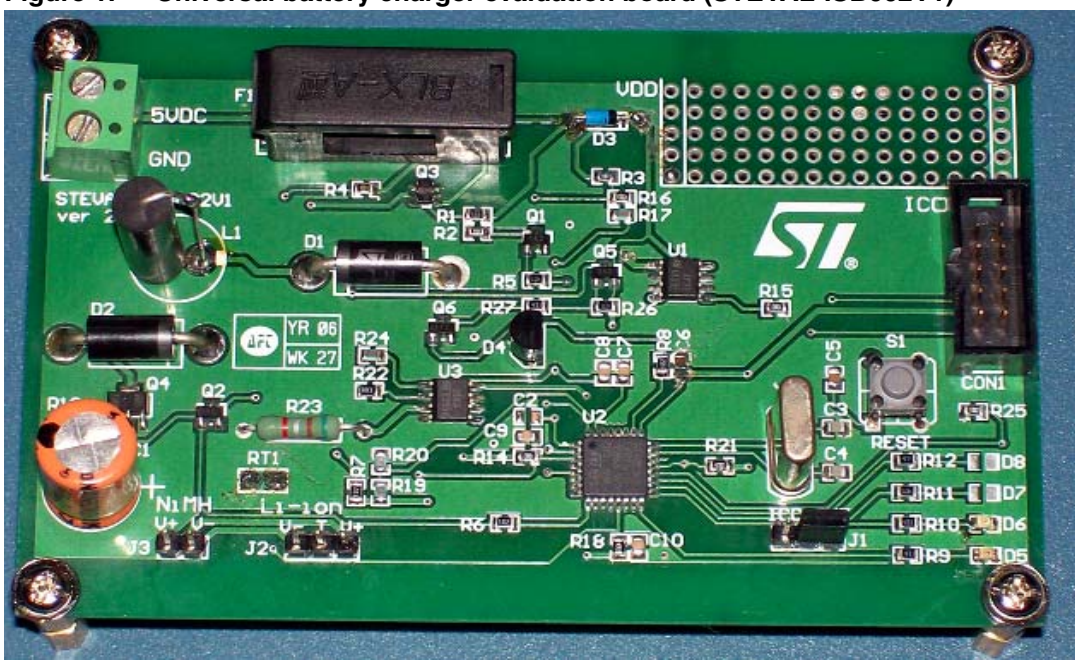
A flexible universal battery charger

Introduction

In everyday life, more and more portable electronic appliances, such as mobile phones, are powered by re-chargeable batteries so the demand for battery chargers for charging these batteries is increasing all the time.

This Application Note describes a cost-effective way to implement an intelligent battery charger for charging Li-ion and NiMH batteries as shown in *Figure 1*.

Figure 1. Universal battery charger evaluation board (STEVAL-ISB002V1)



It is based on a evaluation board built around the ST72324L microcontroller with a demo application code.

While the evaluation board described in this Application note is intended to be used for single cell Li-ion battery or 2 cell NiMH batteries you can customize this charger for a wide range of batteries because of the flexibility of the MCU and of the buck boost converter. The ST72324L MCU was selected for its main features, an embedded 10-bit A/D converter (to efficiently measure voltage, current and temperature), 16-bit timer (to generate PWM signals), main clock controller (to generate a time base signal) and 8 Kbytes of program memory which is more than enough to hold the algorithm for various battery chemistries. You can choose any other MCU that has similar capability. An LED is also used to indicate the charge status.

The evaluation board is powered from a 5 V supply. This supply is purposely chosen to show the application of the modified buck-boost converter. This is because, while a buck converter can be used to charge 2 cell NiMH battery from a 5 V supply, it is not generally suitable for charging a 4.2 V Li-ion battery due to the presence of protection diodes and other components which induce a voltage drop of around 1 V so you can not use a buck converter in this case.

The modified non-inverting buck-boost converter circuit used in this application note needs only one inductor and requires only an extra PWM signal compared to the kind of buck converter that is normally used. By using the switches in different forms, this converter can be used either as a buck converter or as a boost converter. Using the flexibility of the MCU, this converter is capable of charging a wide variety of batteries as can be seen from the evaluation board, where this converter has been used in buck converter mode to charge NiMH batteries, while a combination of buck-boost converter and boost converter modes are used to charge Li-ion batteries. For more details on the buck-boost converter, please refer to AN2389.

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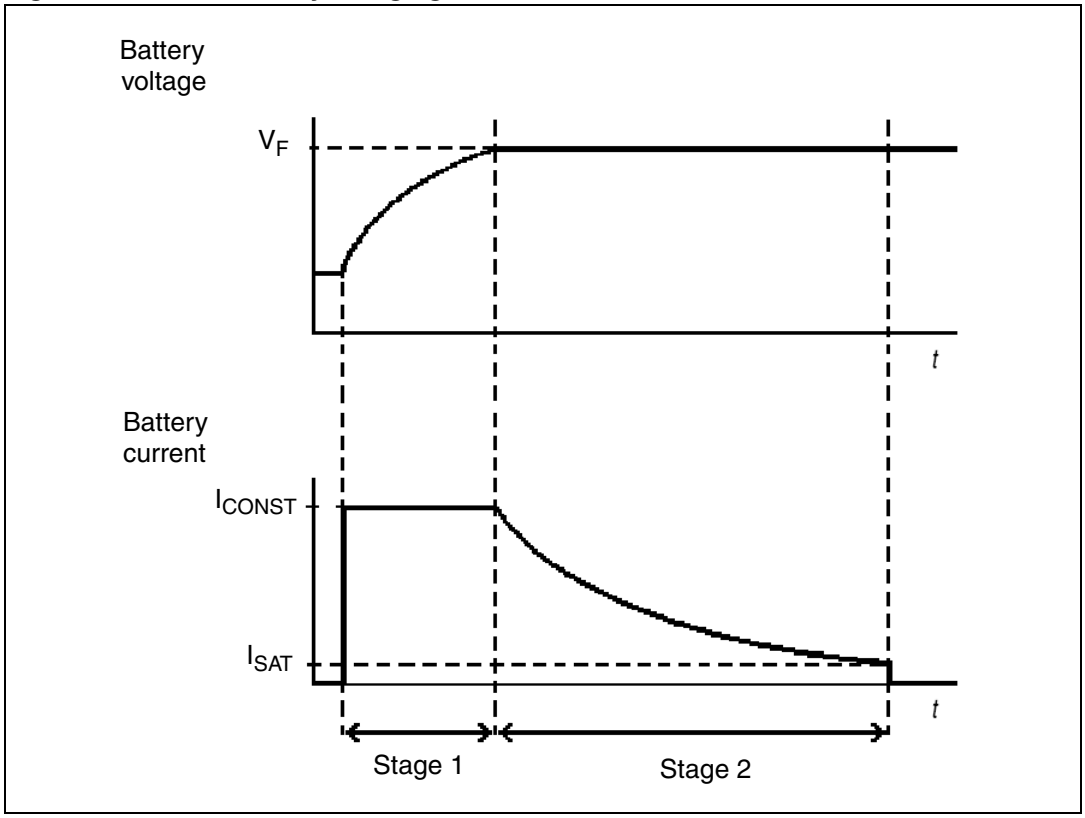
1 Theory of operation

1.1 Li-ion battery charging

Li-ion batteries have a constant current/constant voltage charging algorithm as shown in *Figure 2*.

Figure 2. Li-ion battery charging



During Stage 1 (constant current charge), the charging current is kept at a constant value (I_{const}) until the battery voltage reaches the final cell voltage (V_F). In Stage 2 (constant voltage charge), the voltage is kept constant within this limit by slowly decreasing the current. Charging is stopped when the current drops below the threshold value fixed by the manufacturer (I_{SAT}). This current indicates that the battery is saturated.

In some cases before stage 1, pre-charging can also be done if the battery is fully discharged.

A failure condition occurs if even after a certain time (t_{FAIL}) of fast charging, the battery voltage remains particularly low (under V_{SC}). In this case, charging is stopped and the battery is isolated from the charger. The charger also indicates a battery failure without waiting (protection against short-circuit) if battery current is higher than the threshold I_{FAIL} (equals to the maximum supply current).

If the charging time exceeds a certain expiration value (t_{EXP}), charging is stopped even if the battery is not yet saturated. As the t_{EXP} value is greater than the t_{FAIL} value, the charger indicates that the battery is in good condition and fully charged.

The battery temperature is also monitored. If the battery overheats, charging is suspended until the battery cools down.

Once the battery is saturated, its voltage is still monitored to prevent the battery from discharging completely. If the battery voltage drops below V_{SAT}, charging restarts until V_F is reached again. Charge time is reset when trickle charging starts.

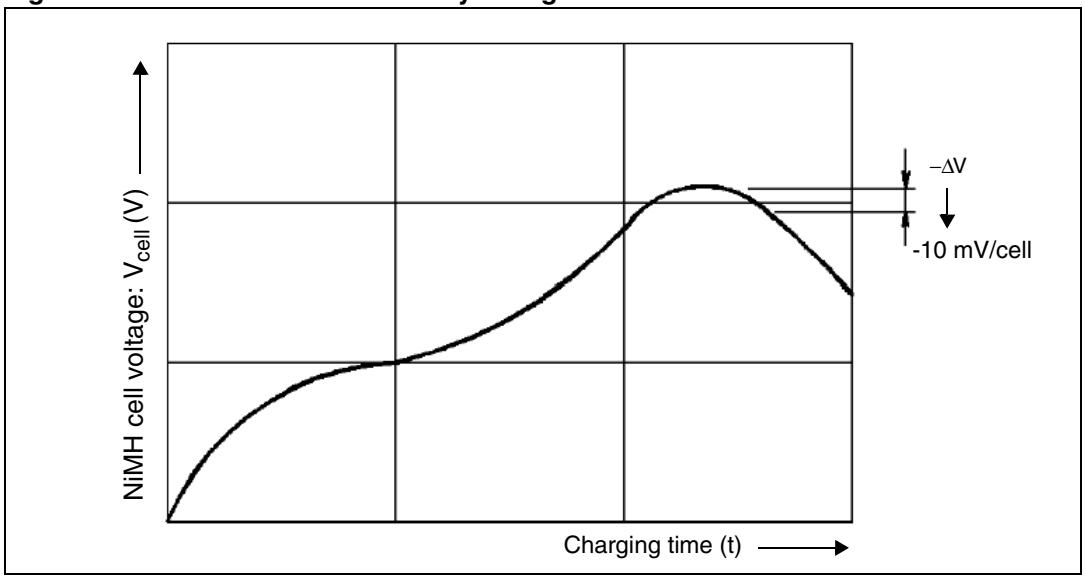
Table 1. Li-ion charge parameters used in the evaluation board

Symbol	Meaning	Value	Unit
V_{MAX}	Maximum charging voltage	4.3	V
V_F	Final battery voltage	4.2	
V_{TRI}	Trickle charge voltage	4.12	
V_{FAST}	Fast charge voltage	3.0	
V_{SC}	Battery failure voltage	1.5	
I_{FAST}	Fast charge current	1000	mA
I_{SAT}	Battery saturation current	20	
I_{FAIL}	Short circuit current	1200	
t_{FAIL}	Battery failure time	30	s
t_{EXP}	Charge expire time	4	h

1.2 NiMH battery charging

The NiMH batteries uses a constant current algorithm as shown in *Figure 3*.

Figure 3. Variation of NiMH battery voltage



The NiMH batteries use constant current charging. The end of charging can be detected by using the following methods.

1.2.1 Negative delta V method

As shown in *Figure 3*, the voltage of the NiMH batteries drops a little at the end of charging. So at the time, when the voltage slope versus time becomes negative, charging is stopped and trickle charging is started.

1.2.2 Zero delta voltage method

This method is a variant of the Negative delta V method. Actually in case of NiMH, there is a very slight drop in voltage (5-10 mV/ Cell) at the end of charging which is very difficult to detect using a 10-bit ADC. Also there is a chance of detecting the wrong end of charging due to noise. So instead of the negative delta voltage, we use a dV = 0 condition for a certain time duration. This gives very good approximations for detecting the end of charging. For this reason, this method is used in the evaluation board example instead of the negative delta method described in *Section 1.2.1*.

1.2.3 Max. temperature detection method

In this case if temperature rises above a threshold, charging is stopped and trickle charging is started.

In this demo the Zero Delta Voltage method is used as the primary technique for terminating the charging. Time Out, Max Voltage and Max Temperature are used as the secondary or back up methods for ending the charging.

Once the battery is saturated, its voltage is still monitored to prevent the battery from discharging completely. If the battery voltage drops below V_{TRI}, charging restarts until V_F is reached again. Charge time is reset when trickle charging starts.

Table 2. NiMH Charge parameters used in the evaluation board

Symbol	Meaning	Value	Unit
V_{MAX}	Max Battery Voltage	1.7/Cell	V
V_{TRI}	Trickle Charge Voltage	1.0V/Cell	
V_{FAIL}	Battery Failure Voltage	0.9/Cell	
I_{CONST}	Constant Charge Current	1000	mA
$I_{TRICKLE_1}$	Initial Trickle Charging Current	250	
I_{SAT}	Battery Saturation Current	65	
I_{FAIL}	Short Circuit Current	1200	
$t_{INITIAL}$	Initial Delay	10	minutes
t_{FAIL}	Battery Failure Time	30	
t_{EXP}	Charge Expire Time	4	h
t_{FAST}	Fast Charging Time	2	

1.3 Slot management

In the demo, there are two different kinds of slots for charging Li-ion and NiMH battery chemistries to show that it can support wide range of batteries. But the positive terminal of one slot is shorted to the positive slot of another battery and similarly for the negative terminals. So the system can support charging of only one battery at a time. Hence you must take care to connect only one battery at a time to the charger. Otherwise the batteries will be shorted together.

1.4 Man-machine interface

The charger periodically checks for battery presence so no button is needed to start or stop charging. An LED is used to indicate the charge status as listed in *Table 3.*.

Table 3. LED slot status color code

LED output	Charging status
OFF	No battery in the slot
Flashing @ 1 Hz	Charging ongoing
Flashing @ 2 Hz	Problem in charging
ON	Battery Present/ Charging Complete

A reset button is also included on the evaluation board to manually reset the application.

2 Evaluation board implementation

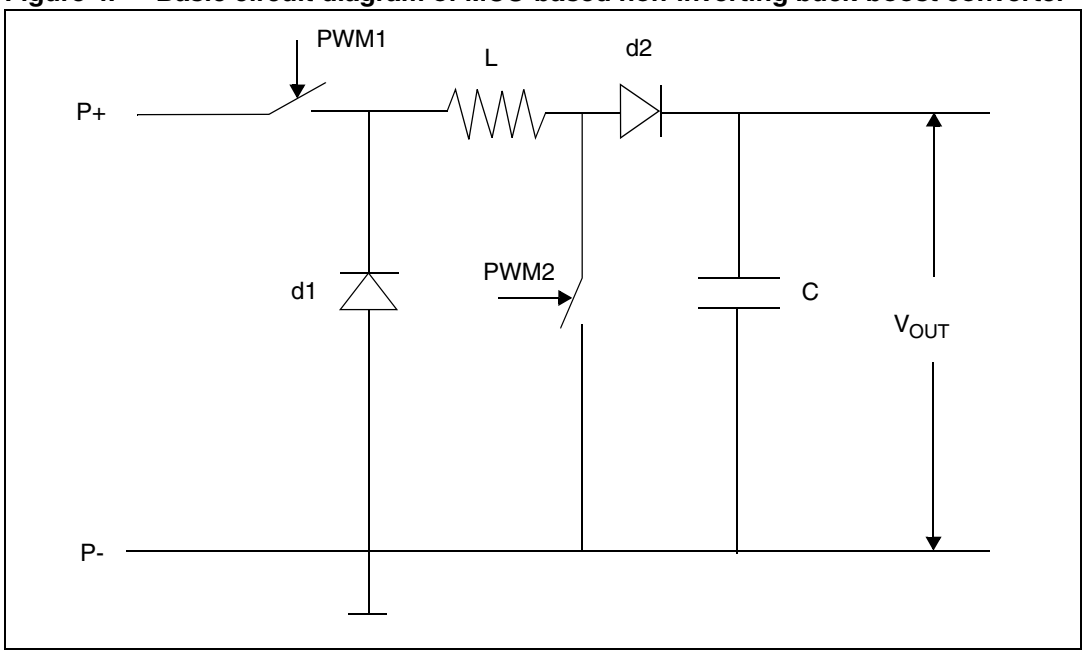
2.1 Charging circuitry

The evaluation board implements a solution with an external low-voltage DC supply.

To obtain a constant voltage or constant current during various stages, the ST7 microcontroller measures the battery voltage (V_{BAT}) and current (I_{BAT}). Along with this feedback, it provides the regulated output power to the battery under charge using a non-inverting buck-boost converter circuit.

The buck boost converter is controlled by 2 PWM signals coming from the microcontroller as shown in basic circuit diagram (*Figure 4*). For more details on the buck/boost converter, please refer to AN2389.

Figure 4. Basic circuit diagram of MCU-based non-inverting buck-boost converter



2.1.1 DC (Buck-Boost) converter component selection

The value of inductor L and capacitor C are selected by the following section. For more detail please refer to AN2389.

Inductor selection

The minimum value of the inductor can be selected by choosing the maximum of the values given by the following two formulae:

$$Lmin = \frac{T * [(Vin - Vsat1) * D1 - Vsat2 * D2 - Vout * (D1 - D2))]}{2 * Iout}$$

$$Lmin = \frac{T * [Vd1 + Vout] * (1 - D1)}{2 * Iout}$$

Here Vsat1 and Vsat2 are the saturation voltages of the two switches Sw1 and Sw2.

Iout and Vout are the maximum output current and voltage respectively.

Vd1 and Vd2 is the voltage drop across diodes d1 and d2.

The duty cycle of the PWM signals driving switch Sw1 (PWM1) and Sw2 (PWM2) are D1 and D2 respectively.

Capacitor selection

The minimum capacitor value can be selected using the following formula to keep the variation in Vout with in 1%:

$$Cmin = \frac{100 * Iout * (1 - D1) * T}{Vout}$$

In practice we take inductor and capacitor values that are 25% more than the values calculated using the above formulae.

2.1.2 Battery discharge protection

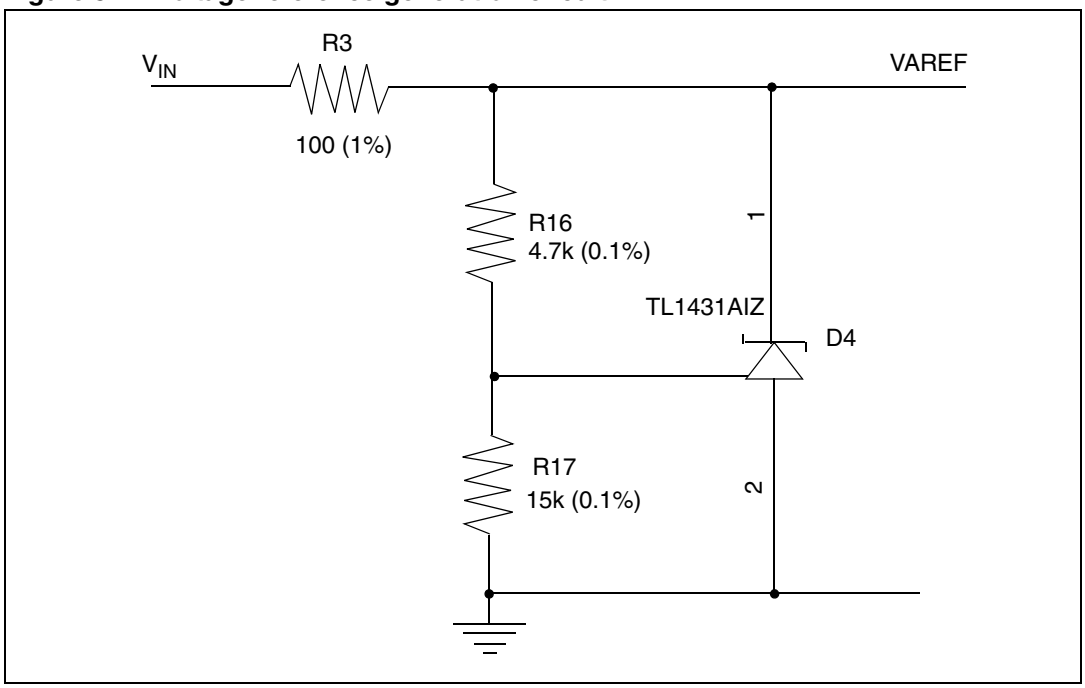
If the charger is not powered on or if the battery is already fully charged, the PNP transistor is kept permanently off which isolates the battery from the charger. Because of series diode available in the buck-boost circuitry there is no reverse current flowing into the charger. Therefore, the battery discharges into the output capacitor and resistive bridge. This allows battery voltage measurement while consuming very little current. Also some leakage current flows through the output capacitor.

2.2 Analog measurement circuitry

2.2.1 Voltage reference generation

In the evaluation board, TL1431 is used to provide the reference voltage for the ADC measurement as shown in *Figure 5*.

Figure 5. Voltage reference generation circuit



This device provides a reference voltage to the ADC and provides a reference of precision better than the 0.5% needed for the battery charger application.

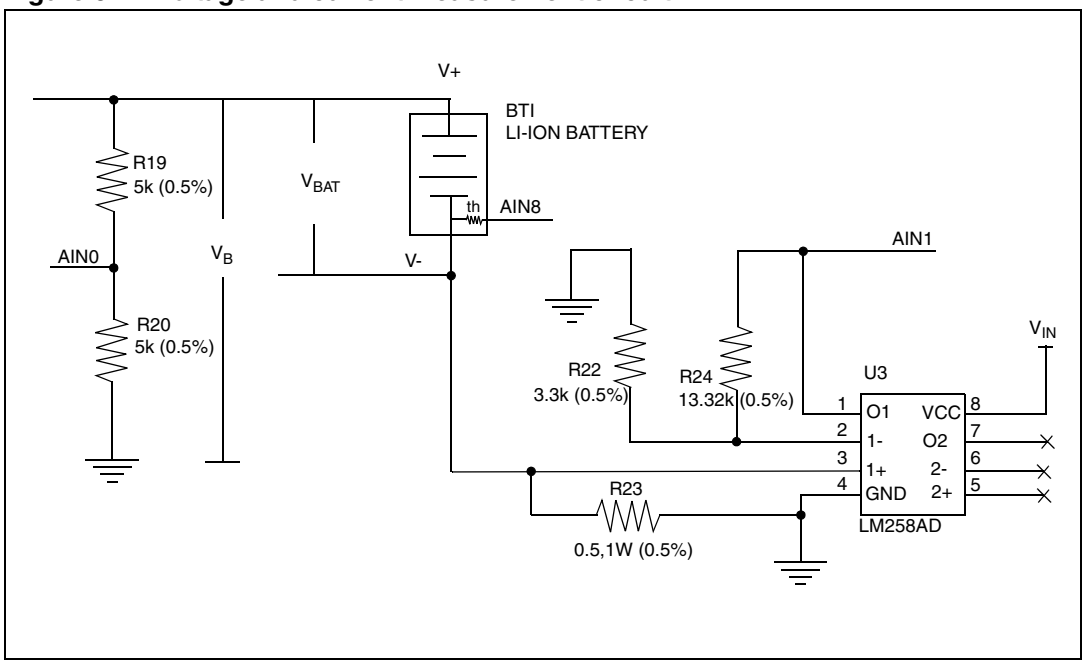
By choosing the appropriate value of R16 and R17 with the proper accuracy, we can provide the required reference voltage to the VAREF pin of the ST7 MCU using the following formula:

VAREF_VALUE = 2.5 V * (1 + R16 / R17)

2.2.2 Current measurement

The current measurement circuit is given in *Figure 6*.

Figure 6. Voltage and current measurement circuit



As shown in the above diagram, a shunt (R_{23}) is connected in series to the battery in order to measure the charging current. The drop across this sense resistor is further amplified by using the OP-AMP (Operational Amplifier) LM258A for better resolution and this amplified voltage is measured by the ST7 microcontroller using ADC channel AIN1. The amplification factor is chosen such that the OP-AMP output has a voltage range between ground and V_{DD}.

2.2.3 Voltage measurement

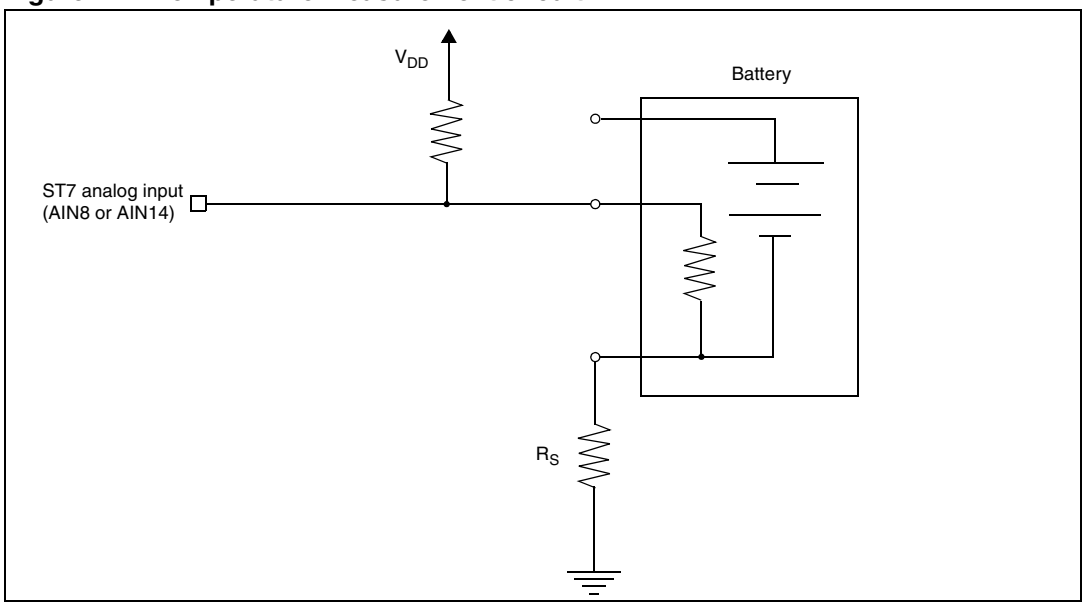
The voltage measurement circuit is also given in *Figure 6* above, where the ST7 ADC channel, AIN0 is used for voltage measurement. In the evaluation board, while the input supply voltage V_{supply} = 5 V, the microcontroller is supplied with V_{DD} = 3.3 V. Therefore, it is not possible to read the battery voltage directly, but this voltage is attenuated by using a resistor bridge (R_{19}, R_{20}). However, this attenuation must still allow us to make full use of the whole ADC input range (0 to V_{DD}).

Note: The ST7 MCU does not measure V_{BAT}, it measures V_B, which is proportional to (V_{BAT} + R_S I_{BAT}). Some calculation must be performed on the conversion results to get the actual battery voltage.*

2.2.4 Temperature sensing

The circuit for the temperature measurement is given in *Figure 7*.

Figure 7. Temperature measurement circuit

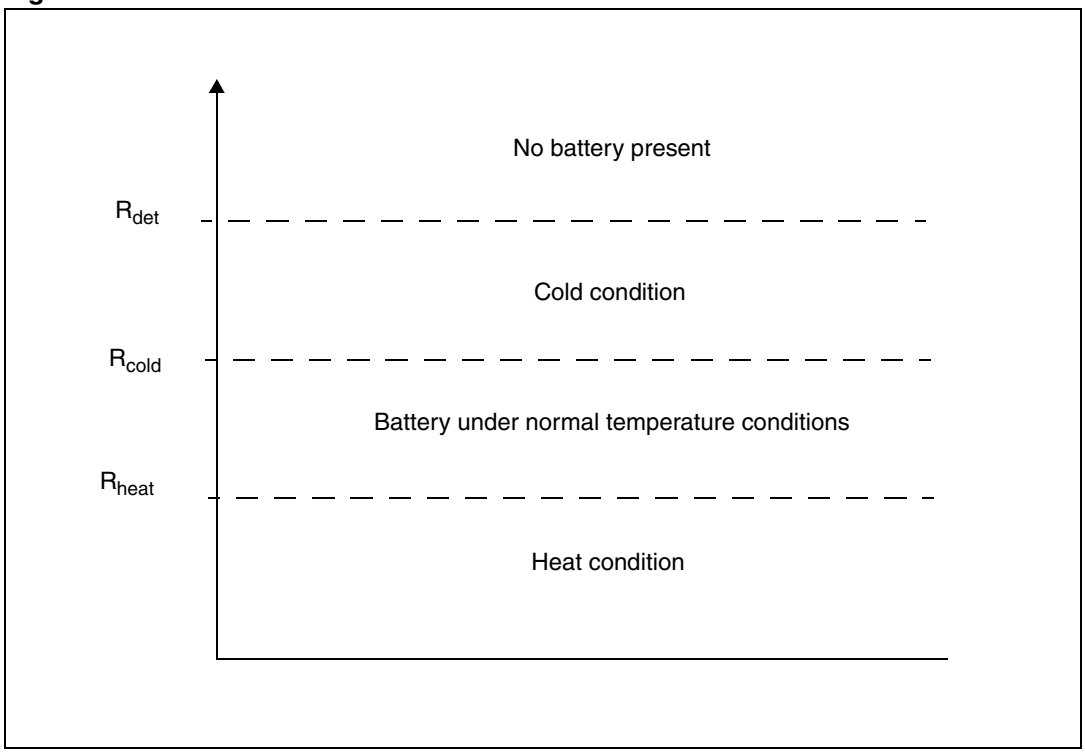


For Li-ion, there is an inbuilt NTC so there is no need for an external thermistor but for NiMH, an external NTC is connected to the negative terminal of the battery.

The same measurement technique is used for both cases. Here the ST7 ADC channel AIN8 is used for the Li-ion temperature measurement and ST7 ADC channel AIN14 is used for NiMH.

For this demo application, we do not need to monitor the temperature very extensively. We only need to detect extreme hot or cold conditions. For this reason, rather than using a look-up table to calculate the temperature, certain predefined parameters are used and these parameters are compared with the temperature reading in terms of NTC resistance which simplifies the calculation.

Figure 8. NTC resistance value indication for Li-ion



Note: 1 Here R_{heat} corresponds to 45°C as the temperature limit for Heat Condition and R_{cold} corresponds to 0°C as the temperature limit for Cold condition for safe charging for both Li-ion and NiMH batteries.

2 R_{DET} is a dummy condition to detect when no battery is in the slot. This threshold is used to detect the battery presence for Li-ion battery only. For NiMH we use a different battery recognition scheme as explained in the following section.

2.2.5 Battery recognition mechanism

In this demo, different techniques are used for Li-ion and NiMH batteries to recognize whether a battery is present in the evaluation board or not.

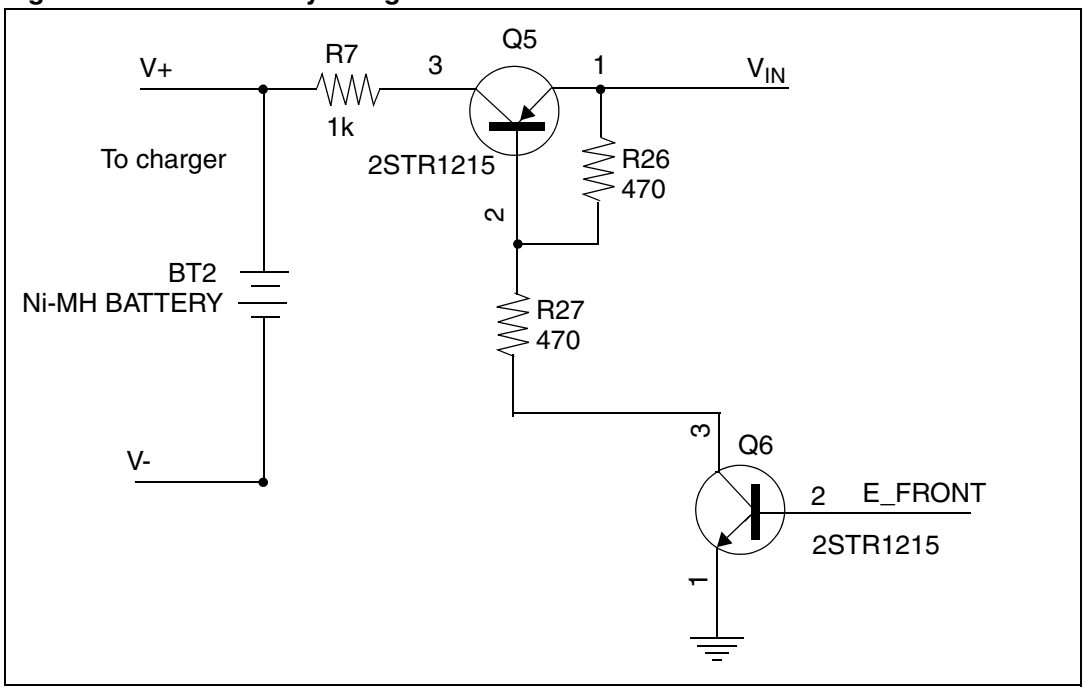
Li-ion battery recognition scheme

As explained in the previous section, for Li-Ion batteries, the in-built NTC thermistor is used to detect battery presence as shown in *Figure 8*

NiMH battery recognition scheme

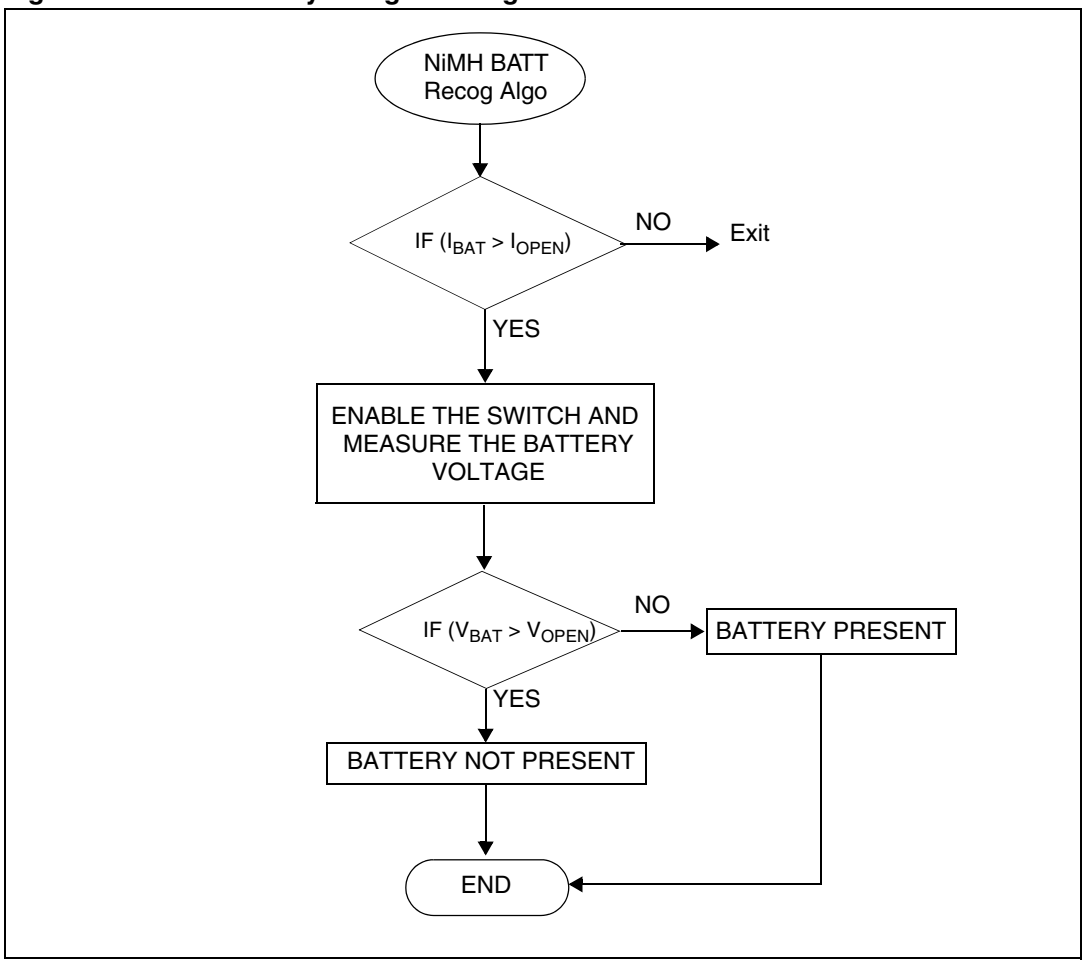
In this case, there is no inbuilt NTC in the NiMH as there is in a Li-ion battery. Hence we can not use the same technique for recognizing a NiMH battery. The NiMH battery recognition circuit is shown in *Figure 9*.

Figure 9. NiMH battery recognition circuit



Here the combination of two transistors works as a switch which is controlled by the E_Front signal coming from the ST7 MCU. The algorithm for NiMH battery recognition is as follows.

Figure 10. NiMH battery recognition algorithm



Here if the battery current is less than a predefined threshold, switch (Q5) as shown in *Figure 9*, is enabled and the battery voltage is measured if the battery voltage is lower than the certain threshold the battery is considered connected otherwise it is considered not to be connected to the evaluation board.

2.2.6 Power supply restrictions

The battery characteristics have a direct influence on the choice of the DC power supply. The supply must be able to drive enough current to charge the battery, even in fast charge mode.

- V_{SUPPLY} must be larger than ($V_{CE}|_{SAT}$ + V_{diode} + V_{BAT_MAX} + R_S* I_{CONST}).

Also the MCU, Buck-Boost DC-DC converter, LED and OpAmp consumption must be taken into account as well. R_S is the sense resistor, indicated as R23 in *Figure 6*.

In this demo, a DC supply providing 5 V and 2 A is chosen which is sufficient to satisfy the above condition.

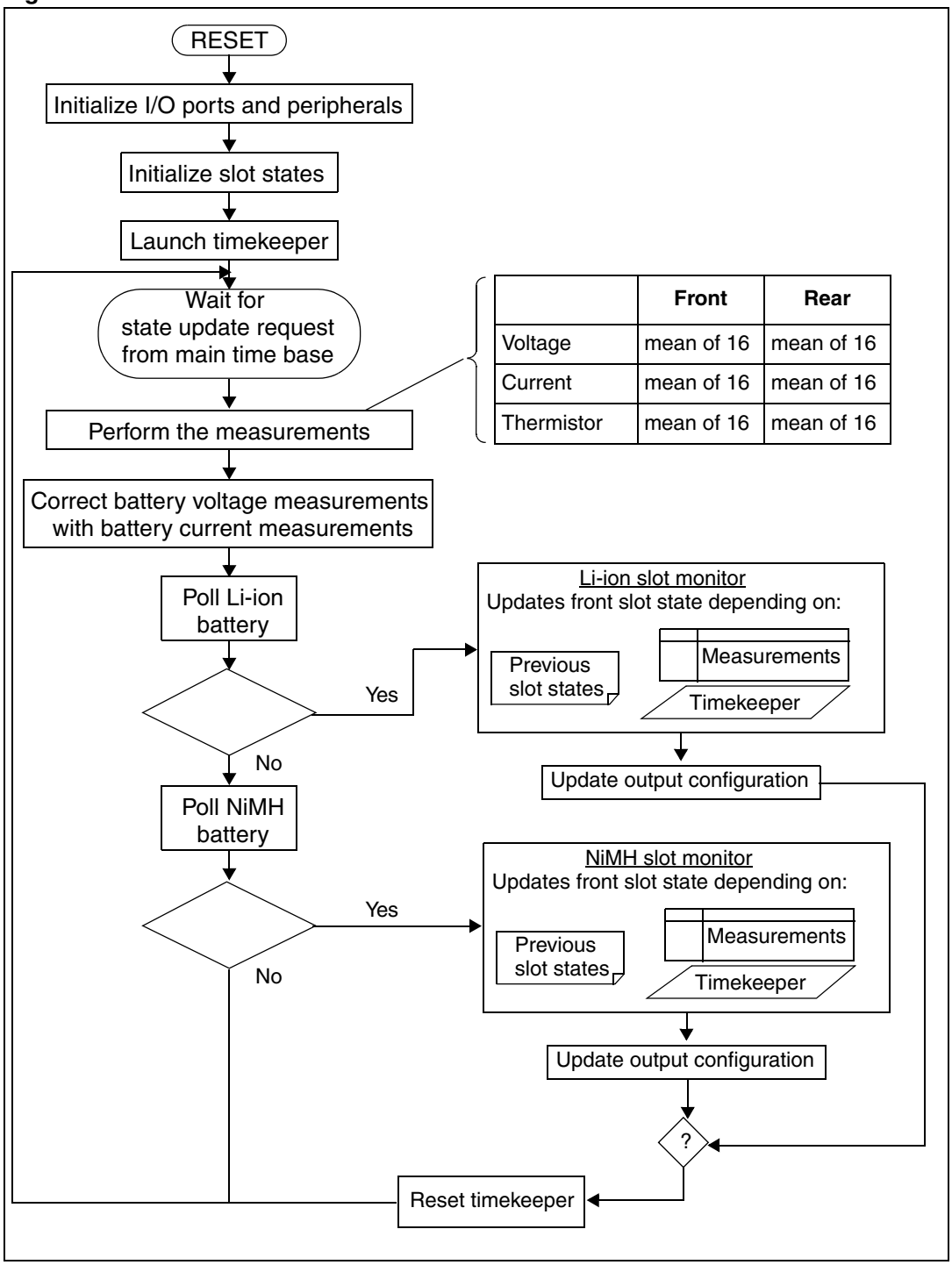
2.3 MCU software

2.3.1 Architecture

The software provided in this demo has state machine architecture. To explain more, various charging states can be defined for each slot. Each slot is driven by its state machine, with some interactions to implement front slot priority.

In order to measure the charge time, a timekeeper is implemented and counters are incremented periodically. Most of the time, slot states are unchanged. This implies that the PWM duty cycle, charge enable signals and LED on/off states are constant. Periodically, the ST7 microcontroller measures the battery current, battery voltage and thermistor voltage of both slots. Using the measurements and the timekeeper values, it updates slot states and the output configuration. If necessary, it resets the timekeeper.

Figure 11. Main software flowchart



2.3.2 Use of the ST7 MCU on-chip peripherals

The time base is generated using the **Main Clock Controller** and the PWM is generated by the **16-bit timer**. In order to minimize supply current, the ST7 core puts itself into WAIT mode between two state updates which is updated @50 ms for Li-ion and @5 s for NiMH but the PWM duty cycle for both is updated @50 ms. The reason for keeping the state update high for NiMH is to detect the end of charging conditions properly which requires monitoring the voltage difference (Zero Delta Voltage Condition) for a long period of time, keeping a low value might result in wrong detection. The selection of state update request for NiMH depends on the user application.

In this demo, the same interrupt condition (Timer reaching zero) also increments the timekeeper counters. This means the timekeeper is synchronized with the state updates.

The timekeeper divides the standard timer frequency. To do this, it has three counters: tick, timeKeeper_Low and timeKeeper_Hi.

Table 4. Charge timekeeper counters

		tick	timeKeeper_Low	timeKeeper_hi
Increment Condition		Timer Zero IT	tick = 0	timeKeeper_Low = 0
Period	General	T_{TMZ}	125 * T_{TMZ}	60,000 * T_{TMZ}
	Evaluation board	2 ms	250 ms	1 min

The **analog to digital converter** (ADC) is used intensively before each slot state update. In most cases, the PWM output cannot be disabled, so due to switching noise, the ADC accuracy is not optimal. To reduce errors, the ADC measures battery voltage, battery current and battery temperature 16 times in a row and takes the average as the final value. The software is able to remove any spurious errors due to noise to avoid any wrong interpretations. The slot state monitoring software works with the mean values.

As explained earlier, battery voltage measurements must be corrected with battery current measurements. These corrections require some computing, performed on the 16-bit words.

2.3.3 State diagrams

A slot can be in one of the nine states as described in following table. These states are updated periodically as described earlier in *Section 2.3.1*

Table 5. Slot state definitions

Name	Meaning	Output configuration	
		Slot outputs	PWM duty cycle
IDLE	Slot empty	Charge disabled, LEDs off	Unchanged
TRI_1	1st Trickle charge state	Charge enabled, LED blinking @ 1Hz	Updated periodically to have $I_{bat} = I_{tri_1}$
CI	Constant current charge		Updated periodically to have $I_{bat} = I_{const}$
CV	Constant voltage charge, duty cycle down		Updated periodically to have $V_{bat} = V_F$
TRI_2	2nd Trickle charge state		Updated periodically to have $I_{bat} = I_{tri_2}$
SAT	Battery saturated	Charge disabled, LED ON	Unchanged
EXP	Charge time expired		
FAIL	Battery failure	Charge disabled, LED blinking @ 2Hz	
HEAT	Charge suspended by overheat		

It is important to understand that this choice of states is only one solution and that there are many possible ways to manage the behavior of the charger.

The state transition diagram is too complex to be shown in a single figure, it has been divided into six parts shown in *Figure 12* through *Figure 17*. In the diagrams, 't' stands for the timekeeper value. The rectangles represent actions performed once during a state transition.

Figure 12. General charging flow – Li-ion charging state diagram (1/3)

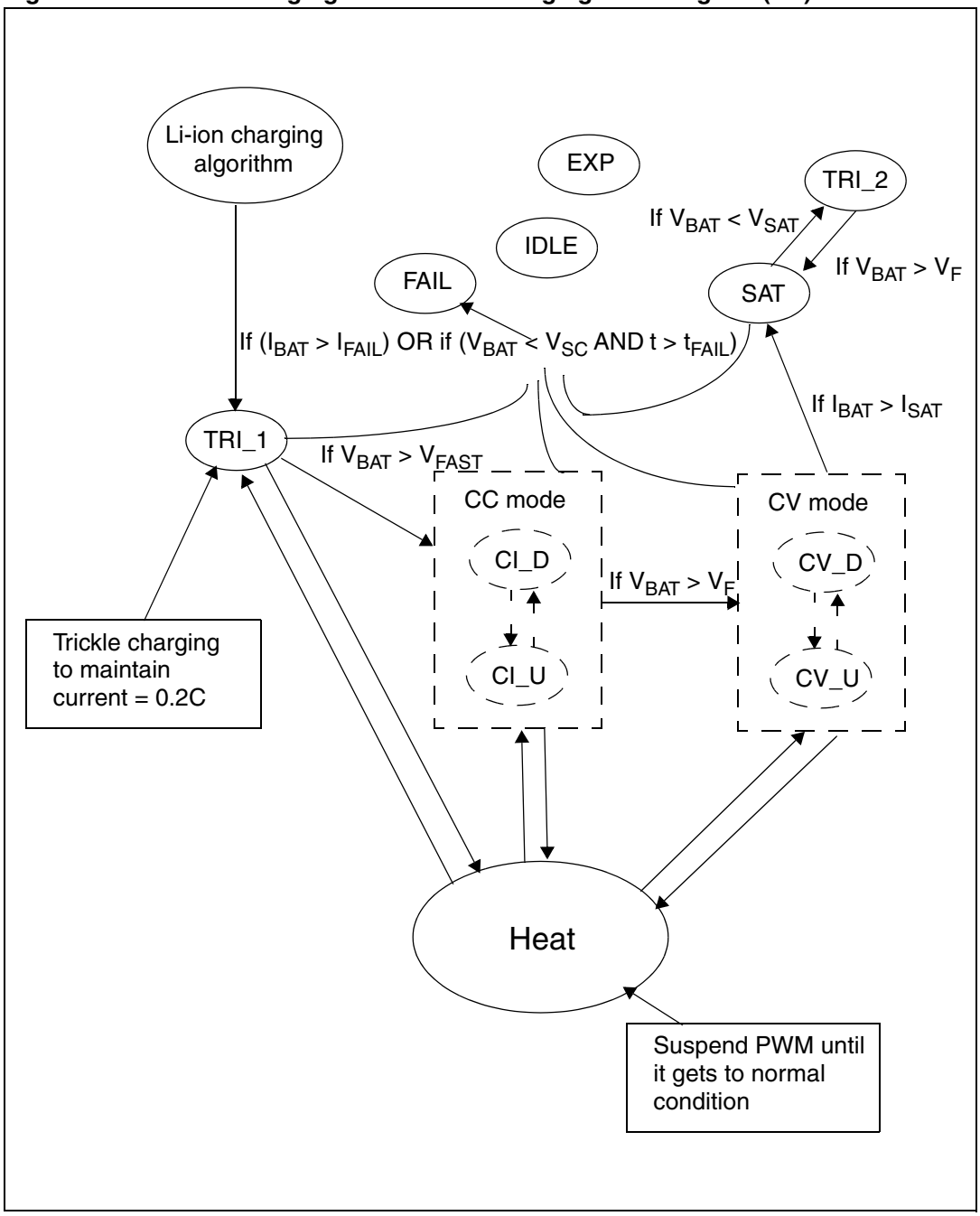


Figure 13. Time expiry condition – Li-ion charging state diagram (2/3)

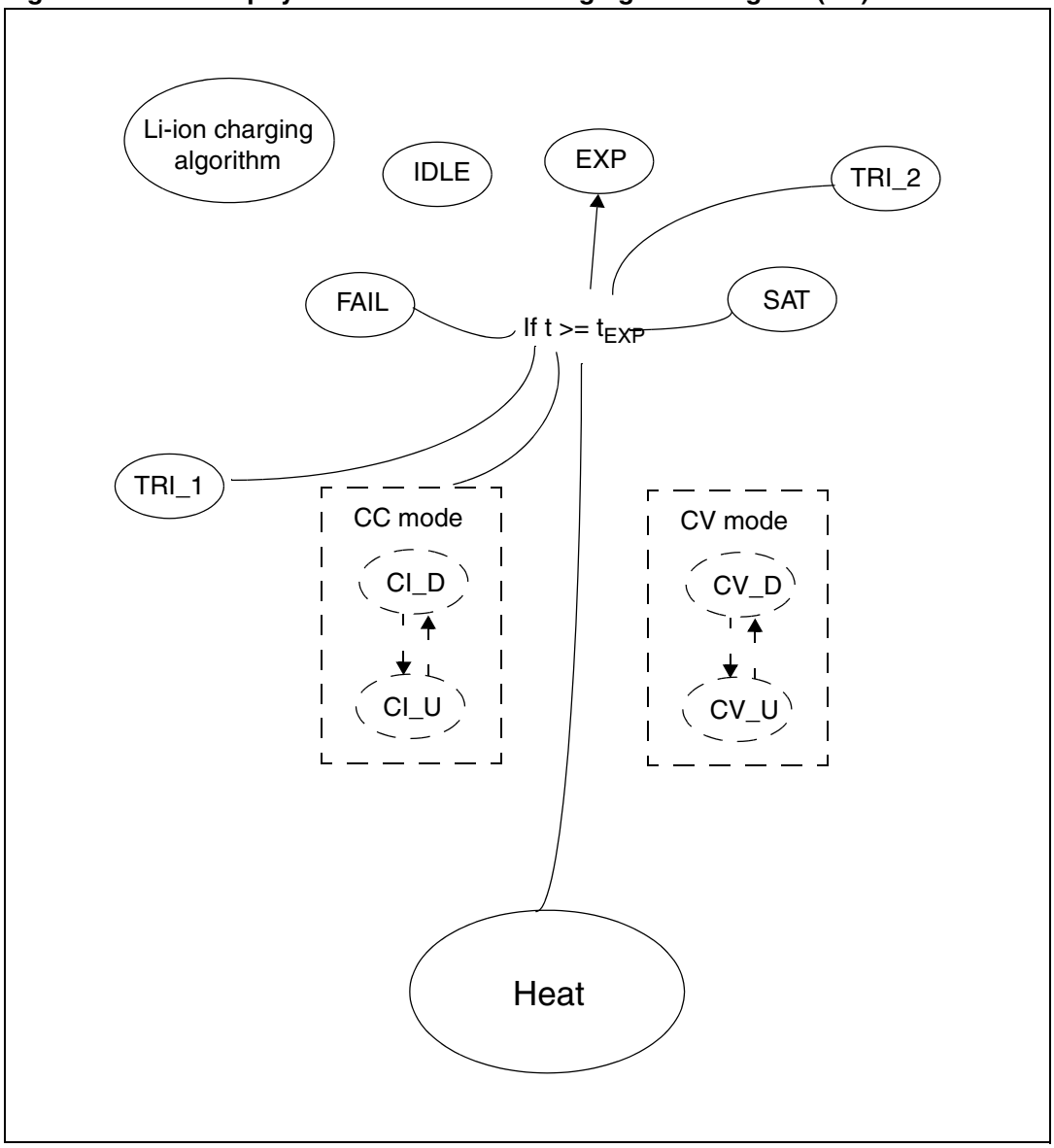


Figure 14. Battery Idle condition – Li-ion charging state diagram (3/3)

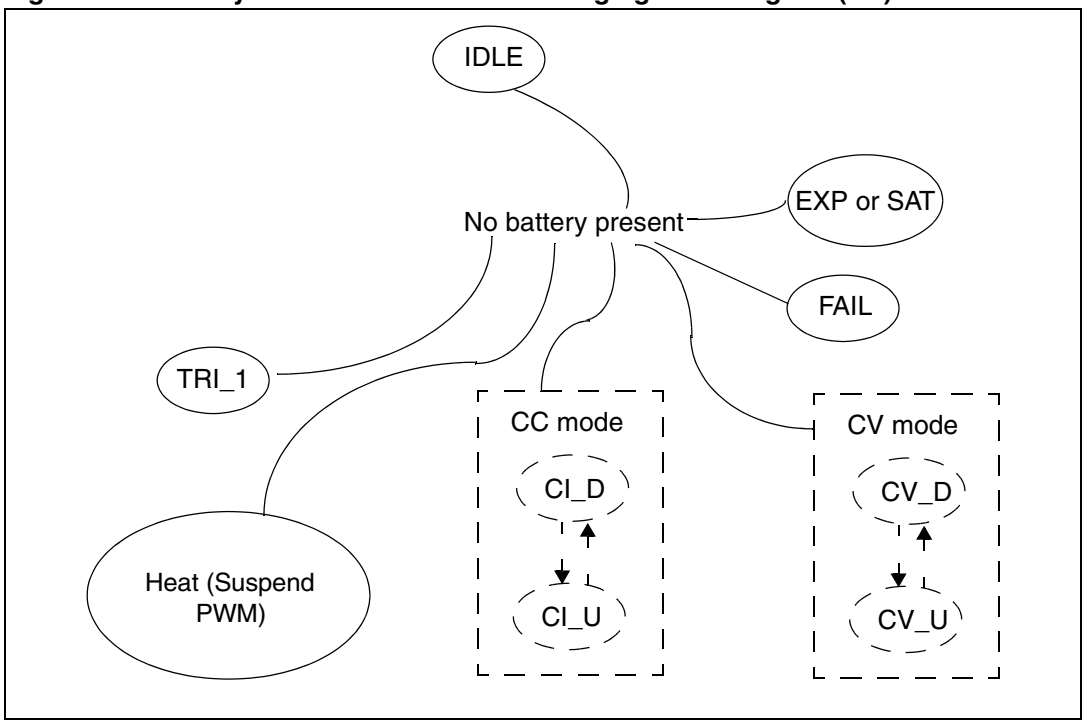


Figure 15. General charging flow – NiMH charging state diagram (1/3)

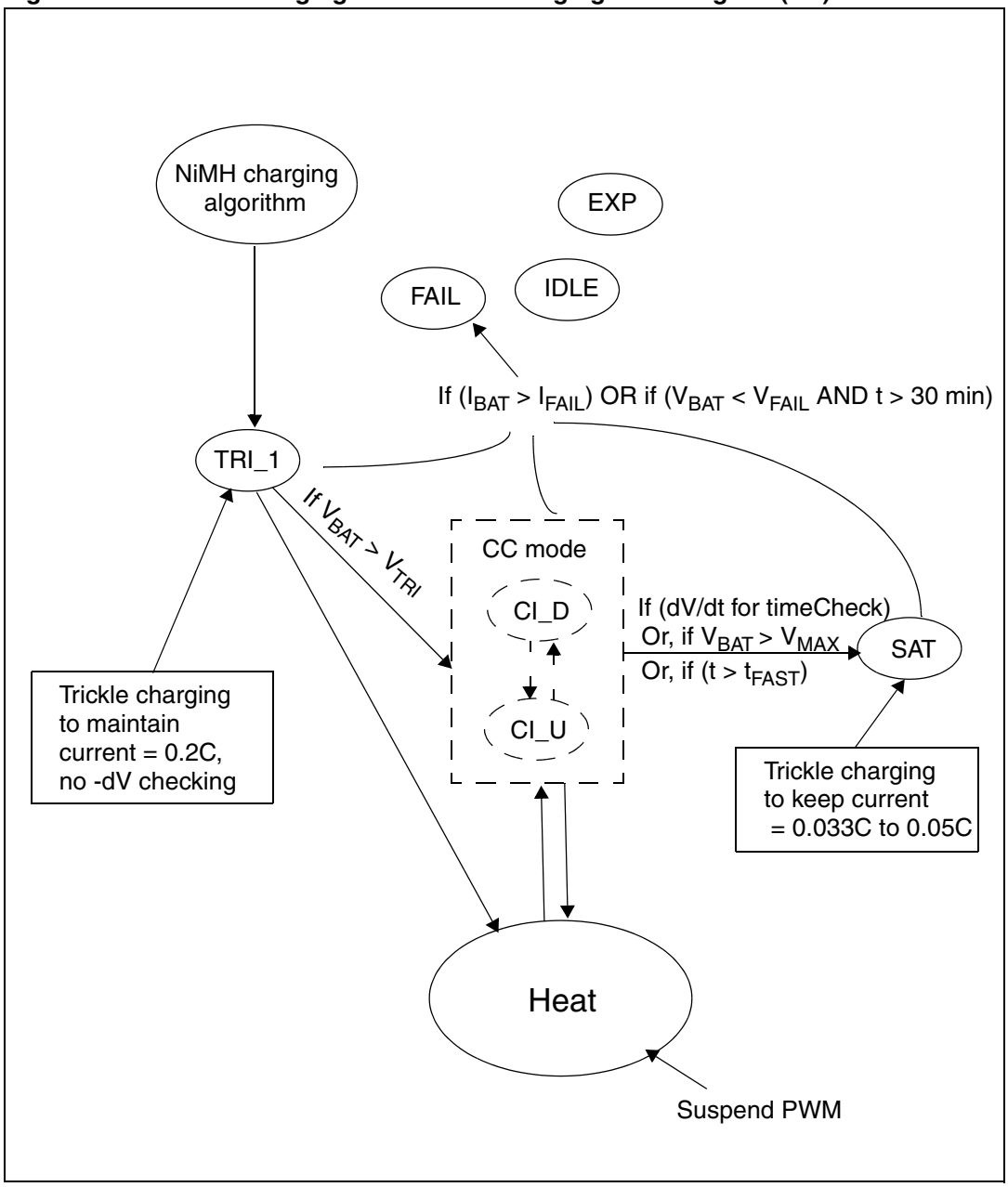


Figure 16. Time expiry condition - NiMH Charging State Diagram (2/3)

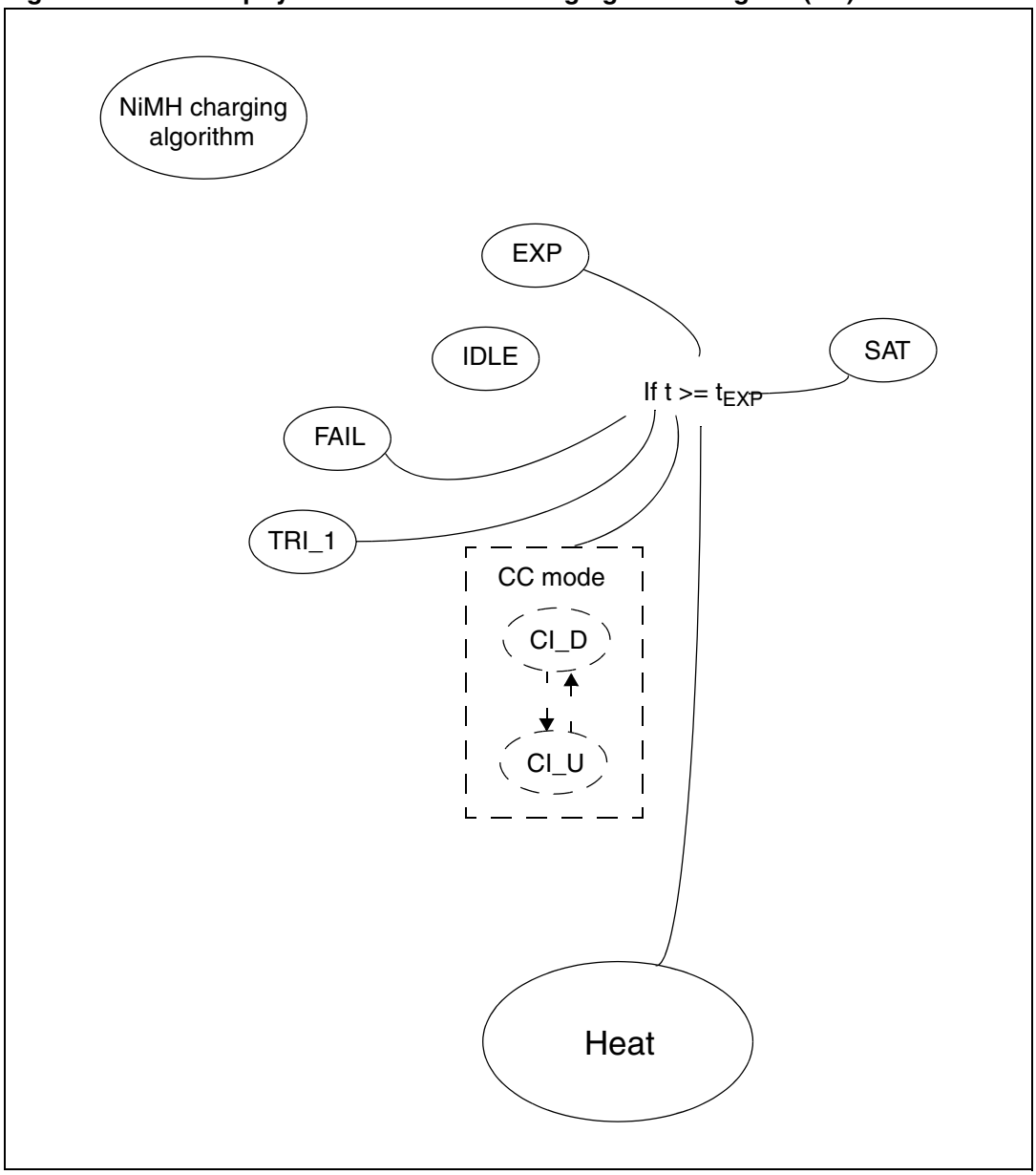
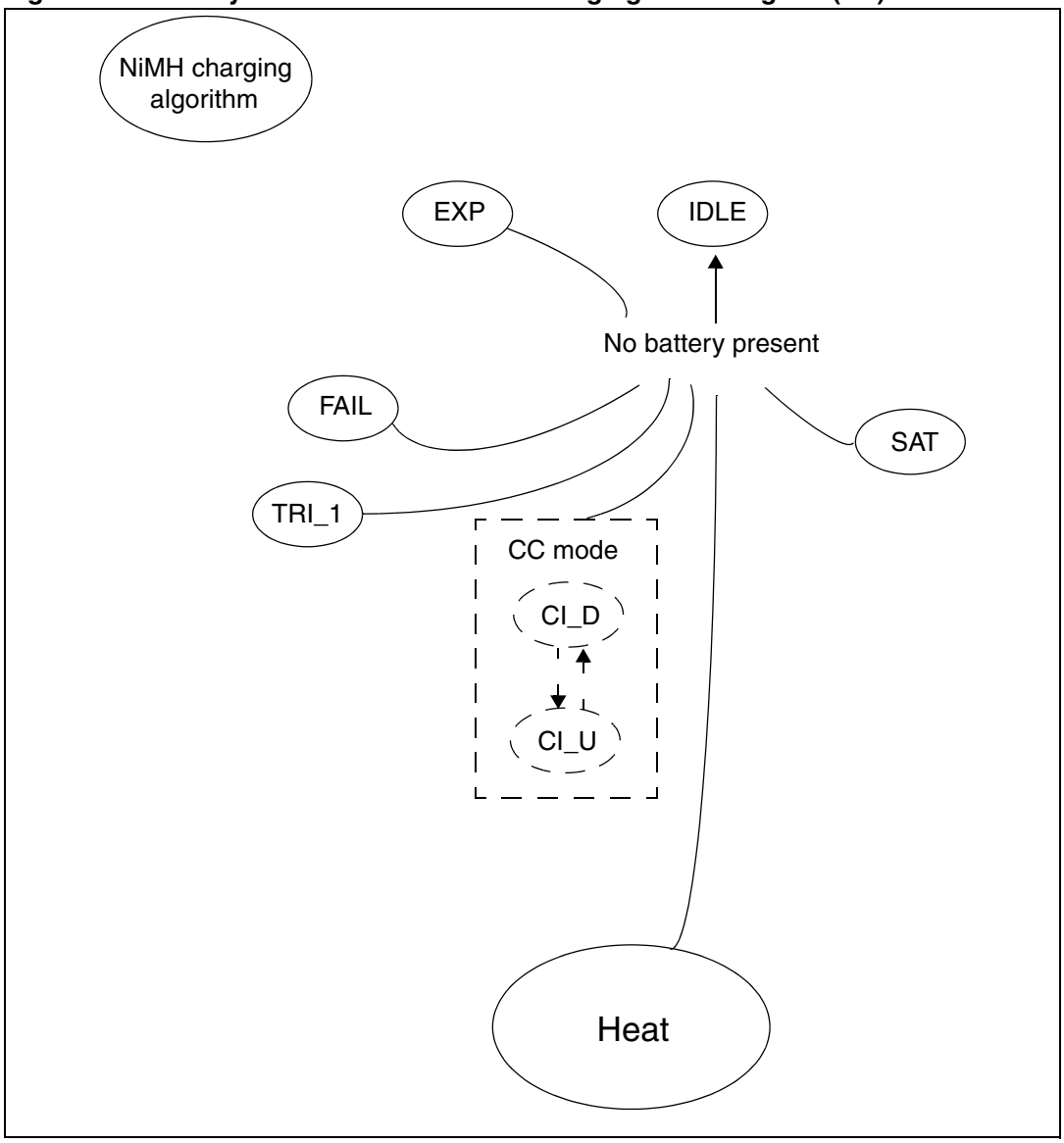


Figure 17. Battery Idle Condition – NiMH Charging State Diagram (3/3)



3 How to use the evaluation board

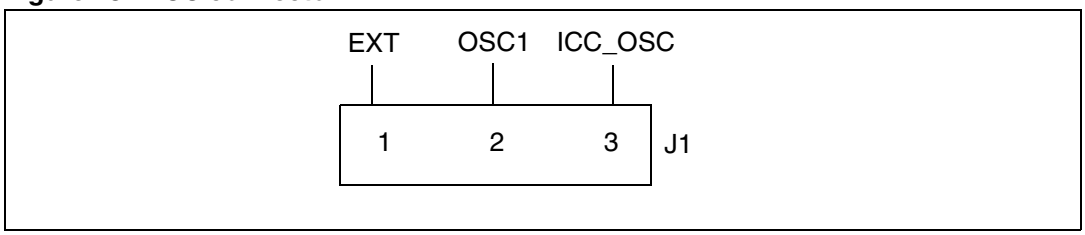
3.1 Connecting the evaluation board

3.1.1 Jumper Connections

The following jumpers must be correctly configured for proper operation of the evaluation board.

J1: This is a 3-pin connector for selecting between ICC clock and resonator clock.

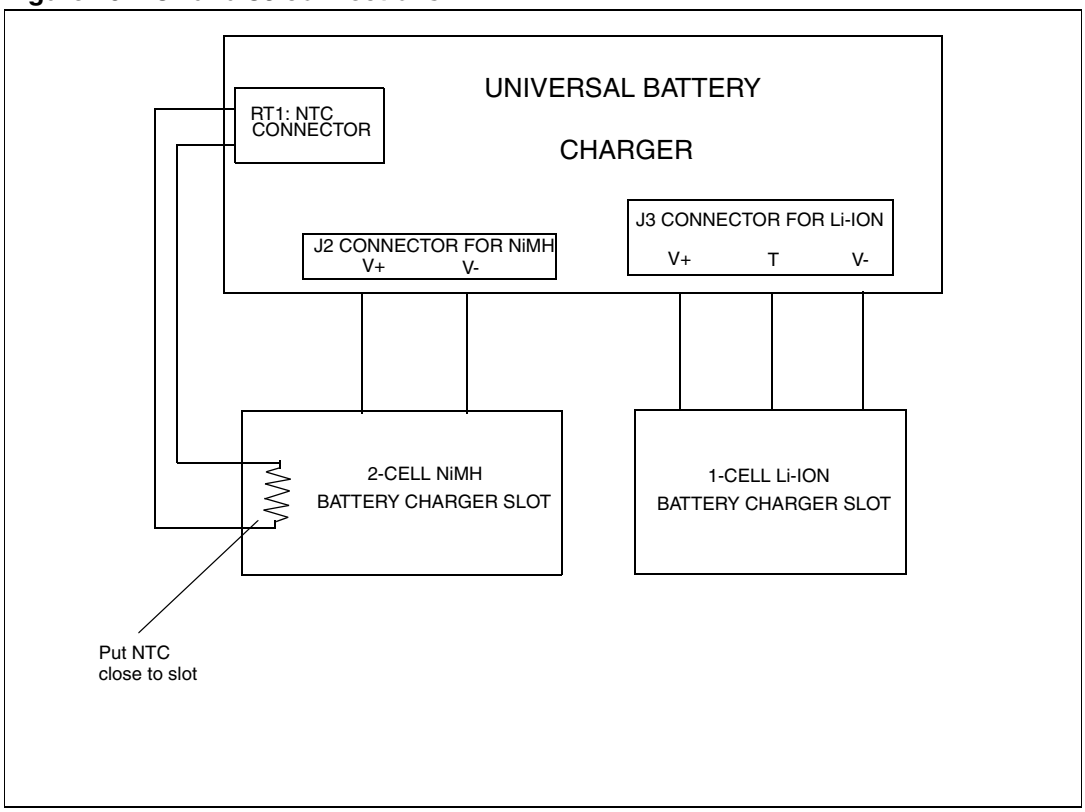
Figure 18. ICC connector



ICC clock is used only when we need to re-program the ST7 microcontroller. For normal operation please short pin 1 and pin 2.

J2, J3: These jumpers are used to connect charger slots for different batteries as shown in *Figure 19*.

Figure 19. J2 and J3 connections



The role of each jumper is as follows:

J2: Used to connect NiMH Battery Charger Slot

J3: Used to connect NiMH Battery Charger Slot

RT1: RT1 is used to connect external NTC. This NTC is put close to the NiMH charger slot to correctly monitor the NiMH battery temperature.

3.1.2 Powering and running the evaluation board

After all the jumpers are connected as described in *Section 3.1.1*, you can connect the power supply. To connect the power supply there is a power jack X1 (5V, Gnd) available on the evaluation board. You need to connect a DC power supply of (5V, 2A) to this connector.

After connecting the power supply, you need to press the Reset button on the evaluation board for correct operation.

Now the evaluation board is in running mode and you can monitor the charging status through LED D5 status as mentioned in *Table 3*.

Note: It is necessary to press the Reset button once after connecting the power supply as the LVD feature is not used in this evaluation board. However the LVD can be implemented in a real application

3.2 Warnings/ Limitations

The user should be aware of the following warnings/limitations when using this evaluation board.

1. Only one type of battery can be charged at a time and there is no protection to prevent shorting the batteries if they are connected simultaneously in both slots. So the user has to make sure to connect only one battery at a time.
2. There is no protection for reverse battery polarity connection but it can be provided on customer request.
3. To minimize noise spikes at the input power supply, please connect a capacitor of 100 - 220 uF between the input power supply and Gnd.

3.3 Example test results with evaluation board

3.3.1 Test environment

In this implementation of the buck-boost converter, the following values are taken into account.

Transistor drop $|V_{CE}|$ (SAT) = 0.2V, Diode drop $|V_d|$ = 0.55 V, L = 75 mH, C = 470 uF, Max V_{sense} = 0.5V, F_{cpu} = 8 MHz, F_{pwm} = 16 kHz and Ambient Temperature = 24 deg C. Also the timer is updated at 500 Hz.

3.3.2 Li-ion battery charger

The following parameter values are used in the Li-ion charger:

Table 6. Li-ion battery charger parameters

SL No	Parameter name	Value
Input Parameter		
1	Input Supply Voltage	5 V
2	Max Input Supply Current	2A
Output Parameter		
3	Max Battery Output Voltage	4.2V
4	Max Output Current	1000 mA

The following values are programmed for the different phases:

1) Precharge Phase:

Here Vbat <= 3.0 V and charging current: 200 mA

2) Constant Current Phase:

Here 3.0 < Vbat < 4.2 V and charging current: 500 mA

3) Constant Voltage Phase:

Here 4.15< Vbat < 4.2 V

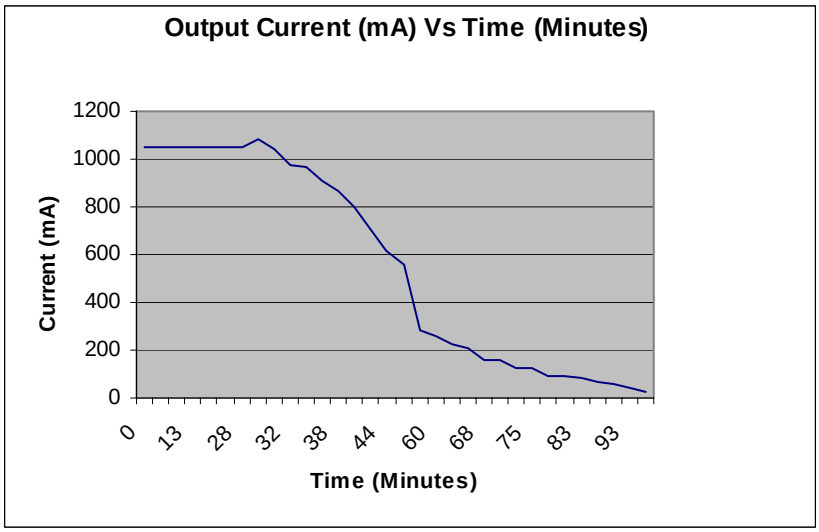
Table 9 shows the results of an experiment with the evaluation board charging a single Li-ion battery.

Table 7. Li-ion test results

SL No	Time (minutes)	Input voltage (V)	Input current (mA)	Output voltage (V)	Output current (mA)
1	0	5	1230	3.9	1050
2	3	5	1230	4	1050
3	8	5	1280	4.05	1050
4	13	5	1350	4.1	1050
5	18	5	1360	4.14	1050
6	23	5	1380	4.18	1050
7	28	5	1390	4.2	1050
8	30	5	1470	4.2	1080
9	31	5	1300	4.2	1045
10	32	5	1270	4.2	975
11	34	5	1260	4.2	968
12	36	5	1150	4.2	906
13	38	5	1070	4.2	867
14	40	5	970	4.2	799
15	42	5	850	4.2	712
16	44	5	720	4.2	616
17	46	5	650	4.2	555
18	58	5	330	4.2	280
19	60	5	310	4.2	260
20	62	5	270	4.2	224
21	65	5	240	4.2	205
22	68	5	200	4.2	160
23	70	5	200	4.2	160
24	73	5	163	4.2	129
25	75	5	150	4.2	123
26	78	5	124	4.2	94
27	80	5	120	4.2	90
28	83	5	110	4.2	81
29	85	5	92	4.2	64
30	88	5	90	4.2	61
31	93	5	74	4.2	45
32	99	5	54	4.2	27

The total time was around 99 minutes in which the constant current phase remained for around 30 minutes. *Figure 20* shows the graph of the output current versus time.

Figure 20. Output Current vs. Time



The variation in the output current was around +/- 10mA and the variation in output voltage was +/- 20 mV.

3.3.3 NiMH battery charger

The following parameter values are used for the NiMH charger.

Table 8. Table 8: NiMH battery charger parameters

SL No	Parameter name	Value
Input Parameter		
1	Input Supply Voltage	5 V
2	Max Input Supply Current	2 A
Output Parameter		
3	Max Battery Output Voltage	1.7 V / cell
4	Output Current	1000 mA

The following values are programmed for the different phases:

1) Pre-charging Phase:

Here Vbat <= 1.0 V and charging current: 0.1 C = 200 mA

Charging time taken by the battery: 10 minutes (approximately)

2) Constant Current Phase:

Charging Current = 1 A and Programmed charging time = 2 Hr

3) Saturation Phase:

Charging Current = 0.03 C = 60 mA, and Expiry Time = 4 Hr.

In this case the C rate is 1000 mA. After the expiry time is over, charging is stopped till a new battery is inserted.

Table 9 shows the results of an experiment for constant current charging phase for a 2 Cell NiMH battery charger.

Table 9. NiMH test results

SL No	Time (minutes)	Input voltage (V)	Input current (A)	Output voltage (V)	Output current (mA)
1	0	5	1.01	3.16	1015
2	5	5	1.01	3.165	1015
3	10	5	1.01	3.168	1015
4	15	5	1.01	3.172	1015
5	20	5	1.01	3.168	1015
6	25	5	1.01	3.16	1015
7	30	5	1.01	3.168	1015
8	35	5	1.03	3.172	1015
9	40	5	1.03	3.175	1015
10	45	5	1.03	3.186	1015
11	50	5	1.03	3.2	1015
12	55	5	1.03	3.206	1015
13	60	5	1.03	3.214	1015
14	65	5	1.03	3.223	1015
15	70	5	1.03	3.231	1015
16	75	5	1.03	3.245	1015
17	80	5	1.05	3.252	1015
18	85	5	1.05	3.264	1015
19	90	5	1.05	3.282	1015
20	95	5	1.05	3.3	1015
21	100	5	1.08	3.35	1020
22	105	5	1.08	3.4	1020
23	110	5	1.08	3.38	1020
24	115	5	1.08	3.37	1020
25	120	5	1.08	3.37	1020
26	125	5	1.08	3.37	1020
27	130	5	1.08	3.36	1020

The variation in the output current was around +/- 10 mA and the variation in output voltage was +/- 20 mV. *Figure 21* shows the graph of the output current versus time.

Figure 21. Output voltage vs. time (in minutes)

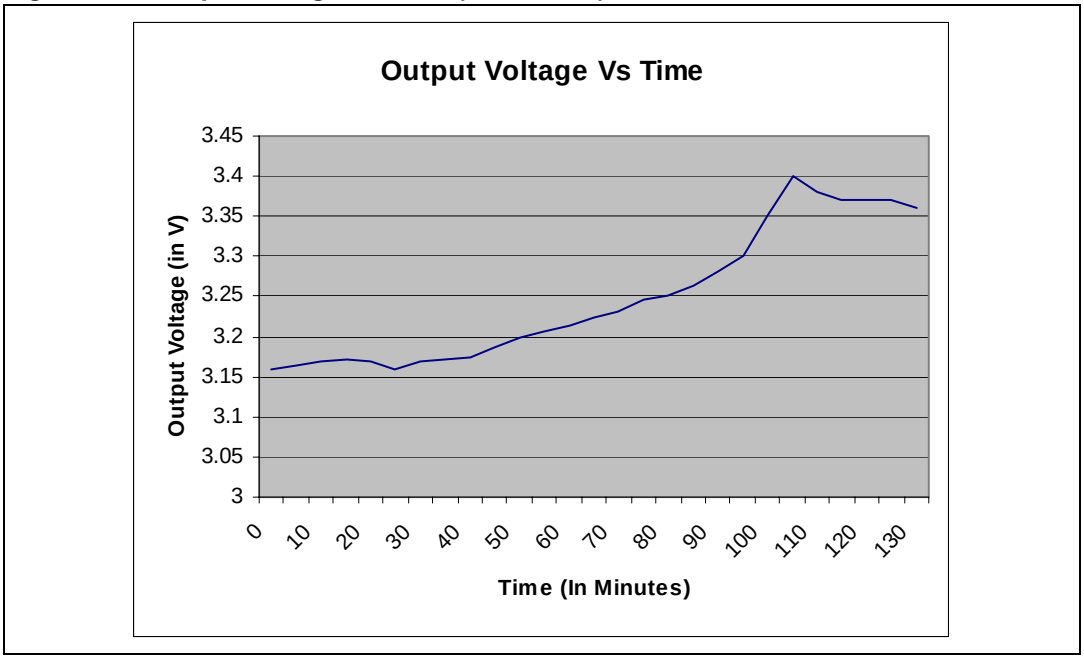


Figure 21 shows the variation in output voltage versus time for the constant current charging phase. Here the programmed time for constant current is increased by 10 minutes just to show the behavior of the charger.

4 Conclusion: a low-cost flexible solution

Everything on the evaluation board has been designed to make it easy to adapt in any way (to other types of battery, new behavior specifications, additional design constraints, etc.).

- The demo is developed with an ST72324L microcontroller device but you can choose another MCU device if you so desire.
- Because of the flexibility of the MCU, you can modify the firmware for wide variety of applications and this is well supported by the flexible non inverting buck boost converter which can adapt to different supply voltages. For example, you could easily make a USB charger to charge a 4.2 V Li-ion battery.
- The firmware is developed in ‘C’ language. So it is easily upgradeable.
- The number of components needed for each slot (charging and feedback) is minimal, so replacing them is inexpensive.
- The code size is approximately 3 Kbytes. The current firmware supports Li-ion and NiMh battery chemistry but it can be easily converted to charge other battery chemistries, for example to charge SLA batteries.
- ST’s low cost PNP and NPN transistors and diodes are used to implement this converter which makes it even more cost-effective.

5 References

[1] AN2389: “An MCU-based low cost non-inverting buck-boost converter for battery chargers”, STMicroelectronics

Appendix A

A.1 Source file organization

The code is written in 'C' language. The Code Size is approximately 3 Kbytes. The source code consists of 3 source files and 3 header files as listed below:

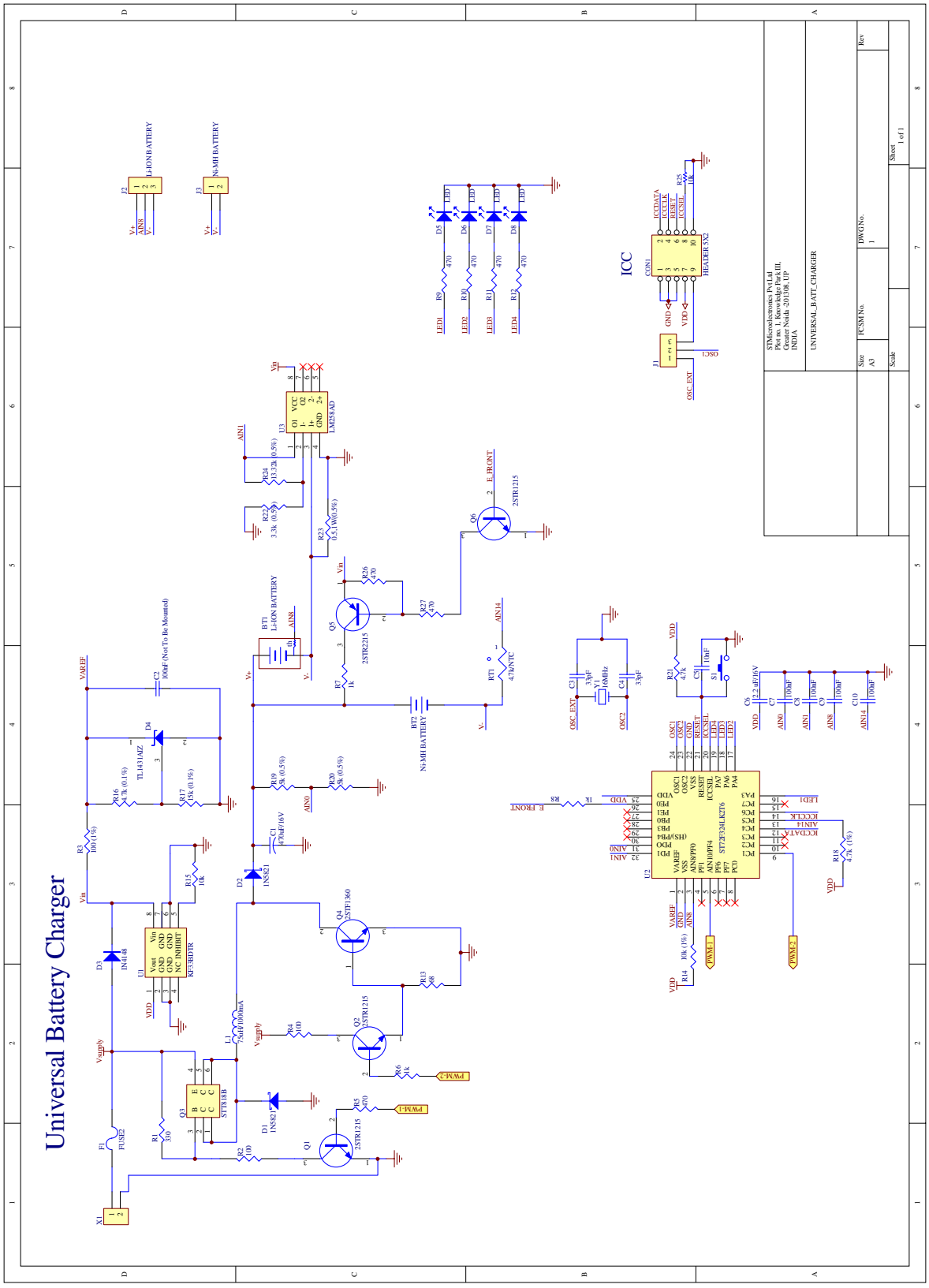
- main.c: it consists of the main subroutine.
- BC_func.c: These files contain the definitions of all the functions used in the main subroutine.
- Interrupt_vector.c: it consists of the interrupt vector mapping files.
- BC_func.h: it consists of the declarations of all the global variables and the functions used in the main.
- ST7lib_config.h: It is the configuration file and also consists of the #define statements for assembly language instructions like 'NOP' etc.
- st7lites2_5_reg.h: It contains the declarations of the hardware registers.

This modular organization makes it easier to perform minor modifications to the software.

Table 10. Examples of minor software modifications

If you want to change…		…only modify…
Voltage thresholds		BC_Func.h
PWM frequency		
State update frequency		
Timing thresholds		
I/O Configuration		BC_InititalizePeripheral() in BC_Func.c
State diagram		BC_SlotMonitor() function in BC_Func.c
	State definitions	
	Transition conditions	
	Transition priority	

A.2 Schematic



A.3 BOM

Table 11. Bill of material

Index	Qty	Reference	Value / Generic Part Number	Package	Manufacturer	Manufacturer's ordering code / Recordable Part Number
1	1	C1	470uF/16V	RB-.2/.4	Any	
2	6	C3, C4, C7, C8, C9, C10	100nF	805	Any	
3	1	C6	2.2 uF/ 16V	805	Any	
4	1	C5	10nF	805	Any	
5	1	CON1	HEADER 5X2	IDC-10B	Any	
6	2	D1, D2	1N5821	DO-201AD	ST	1N5821
7	1	D3	IN4148	DO-35-TH	Any	
8	2	D4	TL1431	TO-92	ST	TL1431AIZ
9	4	D5, D6, D7, D8	LED	LED	Any	
10	1	F1	FUSE2	FUSE	Any	
11	1	J1	CON3	SIP-3	Any	
12	1	J2	CON3	SIP-3	Any	
13	1	J3	CON2	SIP-2	Any	
14	1	L1	75uH/1000mA	IND	Any	
15	3	Q1, Q2, Q6	2STR1215	SOT-23	ST	2STR1215
16	1	Q3	STT818B	SOT23-6L	ST	STT818B
17	1	Q4	2STF1360	SOT-89	ST	2STF1360
18	1	Q5	2STR2215	SOT-23	ST	2STR2215
19	1	R1	330	805	Any	
20	7	R5, R9, R10, R11, R12, R26, R27	470	805	Any	
21	1	R13	68	805	Any	
22	2	R14, R15	10k (1%)	805	Any	
23	1	R16	4.7k (0.1%)	805	Any	
24	1	R17	15k (0.1%)	805	Any	
25	1	R18	4.7k (1%)	805	ST	
26	2	R19, R20	5k (0.5%)	805	Any	
27	1	R2, R7	100	805	Any	

Table 11. Bill of material

Index	Qty	Reference	Value / Generic Part Number	Package	Manufacturer	Manufacturer's ordering code / Recordable Part Number
28	1	R21	4.7k	805	Any	
29	1	R22	3.3k (0.5%)	805	Any	
30	1	R23	0.5, 1W (0.5%)	RES Axail	Any	
31	1	R24	13.32k (0.5%)	805	Any	
32	1	R25	10k	805	Any	
33	1	R3	100 (1%)	805	Any	
34	1	R4	100	805	Any	
35	3	R6, R8	1k	805	Any	
36	1	RT1	4.7k/NTC	RAD-0.1	Any	
37	1	S1	SW-PB	PUSH	Any	
38	1	U1	KF33	SO-8	ST	KF33BDTR
39	1	U2	ST72F324L	TQFP-32	ST	ST72F324LK2T6
40	1	U3	LM258AD	SO-8	ST	LM258AD
41	1	X1	Power Connector	Euro 2 pin	Any	
42	1	Y1	16MHz	XTAL-1	Any	

Revision history

Table 12. Document revision history

Date	Revision	Changes
21-Aug-2007	1	Initial release.

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